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Risø-R-739(EN)

Nuclear Safety Research Department

Annual Progress Report 1993

Edited by B. Majborn, K. Brodersen, A. Damkjær and C.F. Højerup

Risø National Laboratory, Roskilde, Denmark
February 1994

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Abstract The report describes the work of the Nuclear Safety Research Department during 1993. The activities cover health physics, reactor physics, operation of the small reactor DR1, and radioactive waste management.

Lists of staff and publications are included together with a summary of the staff's participation in international committees.

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Contents

1 Introduction

The Nuclear Safety Research Department is engaged in research and development concerning radiation protection, reactor safety and radioactive waste. The department is organized in three sections: The Health Physics Section, the Reactor Physics Section (with the reactor DR1) and the Waste Management Section.

In addition to its research and development activities, the department is involved in supporting activities related to the safe operation of the nuclear facilities at Risø. The activities include personnel dosimetry, maintenance and calibration of health physics instruments, emergency preparedness, reactor physics support to the reactor DR3, criticality evaluations, and participation in safety committee work. The Waste Management Section is responsible for the safe handling and storage of radioactive waste from Risø as well as from other Danish users of radioactive materials.

The work of the department involves a close collaboration with the Danish nuclear authorities: the Emergency Management Agency and the National Institute of Radiation Hygiene, and also with Danish and foreign universities and research institutes, especially the Technical University of Denmark and partners in research programmes supported by the CEC (Commission of the European Communities) and by NKS (the Nordic Nuclear Safety Research Programme).

As a part of the co-operation between Risø and the Emergency Management Agency, Risø has assisted the agency in preparing a general nuclear emergency preparedness plan for Denmark, which came into force on April 1, 1993.

This report describes the work of the Nuclear Safety Research Department in 1993 with an emphasis on the results of the research and development activities. Lists of staff and publications are included together with a summary of the staff's participation in international committees.

2 Health Physics

The Health Physics Section is engaged in research and development in dosimetry, instrumentation for radiation measurements, and radon physics. In addition the section is responsible for personnel dosimetry and for the maintenance of health physics instruments at Risø. The section also contributes to the Danish emergency planning and preparedness activities.

2.1 Dosimetry

2.1.1 Personnel Dosimetry

Risø's personnel dosimetry service covers the individual monitoring of the personnel at Risø and at the Niels Bohr Institute Tandem Accelerator. Only persons actually involved in radiation work are equipped with a personal dosemeter. In areas where the use of personal dosemeters is not required, the radiation levels are controlled through an extensive area-monitoring programme using thermoluminescense (TL) dosemeters.

The main statistics of the dosimetry service for 1993 are shown in Table 2.1 and in Figure 2.1.

Table 2.1. Statistics for monitoring of Risø personnel in 1993

No. of persons monitored	964
No. of persons receiving external doses above 0.2 mSv (the registration level)	224
No. of persons receiving internal doses from intake of tritiated water	55
Total collective dose to the monitored personnel:	
External doses	319 mSv
Internal doses	13 mSv
Total	332 mSv

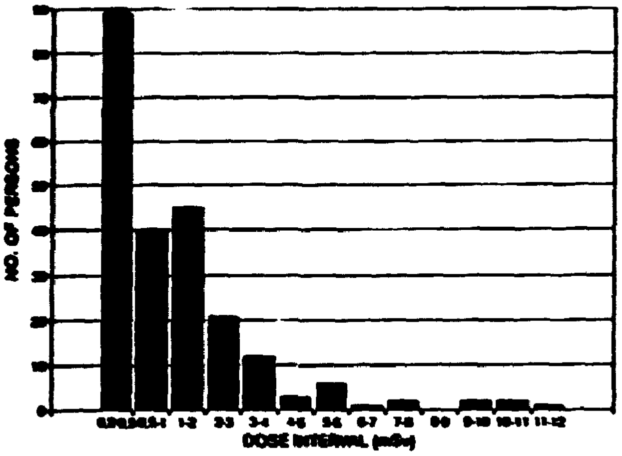


Figure 2.1. Distribution of whole-body doses (effective doses) for the Risø personnel in 1993.

2.1.2 EU Technical Recommendations on Individual Monitoring

In collaboration with other European laboratories, the dosimetry group assisted the EU in preparing a document on technical recommendations for monitoring the exposure of individuals to external radiation. A final draft has been forwarded to the EU, and the document is expected to be published soon.

Results from a joint experiment carried out by three laboratories (TNO, the Netherlands, NRPB, England, and Risø) to demonstrate the adequacy of the recommendations prescribed in the EU document were further evaluated. The dosimetry systems tested were essentially the TLD systems operated on a routine basis at the three laboratories. The experiment focused on the energy and angular response characteristics of the dosemeters and involved 192 dosemeters of each system which were irradiated with 16 photon energies at 4 different angles of incidence. The set-up of dosemeters for each irradiation is illustrated in Figure 2.2. The results of the experiment showed that all three dosimetry systems meet the criteria for photon radiation over the entire energy range from 15 keV to 1.25 MeV.

2.1.3 Dosimetry of Beta and Low-Energy Photon Radiations

This work concerns the development of standard calibration facilities and standardised measurement and calculation procedures for dosimetry of weakly penetrating radiations. The work is carried out in collaboration with nine other European laboratories in a joint EU project.

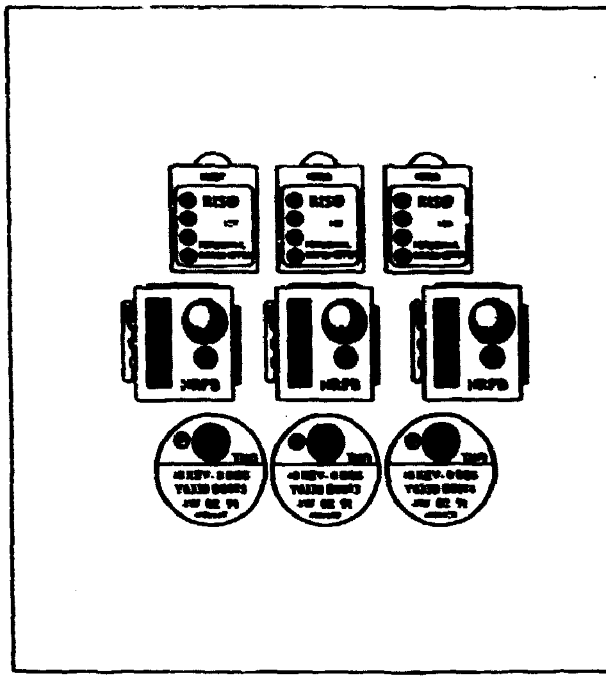


Figure 2.2. Dosemeter set-up on a 30 cm x 30 cm x 15 cm perspex phantom for irradiation at different photon energies and angles of incidence.

The extrapolation chamber is used as a standard measurement instrument for the determination of dose rates in beams of weakly penetrating radiations. In collaboration with the Engineering and Computer Department at Risø a fully automated computer-controlled extrapolation chamber measurement set-up was established. In addition to the current produced by the ionising radiation the system also registrates data on environmental parameters important for the dose determination, e.g. temperature, pressure and relative humidity. A software package was developed which is used to calculate the dose rate on the basis of the measured data.

One of the objectives of the joint EU project is to establish beta calibration facilities which conform with the specifications for ISO Series 2 references. The ^{14}C radionuclide, which is one of the beta emitters recommended for the ISO Series 2 group, was studied for use as a beta calibration source at Risø. The source construction used was a 220 mm × 220 mm × 0.9 mm perspex sheet with the ^{14}C radionuclide incorporated into the acrylic material. The source contains 18.5 $MBq{\cdot}g^{-1}$ perspex with an emission rate of 2×10^4 $s^{-1}cm^{-2}$ beta particles from the surface of the source. The thickness of the source is larger than the maximum range of the ^{14}C beta rays and therefore the energy spectrum obtained is equivalent to that for an infinitely thick source. Shields of perspex positioned in front of the source enabled different sizes of the source to be studied. The source was positioned in a special holder enabling the radiation field to be measured by extrapolation chamber, geiger tubes and solid state detectors. The results showed that the ISO requirements on homogeneity and maximum beta energy are fulfilled for distances up to at least 10 cm from the source.

A number of intercomparison exercises with beta sources have been performed by European dosimetry laboratories in order to ensure consistency of standard beta dosimetry among the laboratories. The results from one intercomparison organised by EURADOS showed unexpectedly high differences between the results of the various participants, so supplementary measurements have been initiated to identify the cause of this discrepancy. A final report on this study is expected to be ready during 1994.

The dosimetric characteristics of the Chinese LiF:Mg,Cu,P TL material for beta dosimetry have been further investigated. Thin detectors consisting of crystals of the TL material fixed onto a polyamide (kapton) foil were irradiated at different incident angles in a ^{147}Pm beta radiation field. A flat angular response curve was observed, but because of significant attenuation of the beta radiation occurring in the grains of the TL crystals, the response of the detectors is only 50% of that observed from exposure to ^{60}Co radiation. Some improvement of the response characteristics may be achieved by using smaller grain sizes.

2.1.4 Control of Irradiated Spices

The dosimetry group assisted the National Food Agency of Denmark and the FDB company with TL measurements of a number of selected samples of spices for irradiation control.

2.1.5 Calibration of Gamma Irradiation Facilities (Gamma Cells)

The dosimetry group used TL dosimetry for calibration of two ^{137}Cs gamma cells intented for use for irradiation of blood samples. The work comprised dose homogeneity studies of the radiation field as well as determination of dose-time calibration curves.

2.2 Development of Instruments and Methods

2.2.1 Photo-Stimulated Luminescence

Development of a compact design for monochromatic photo-stimulated luminescence (PSL) measurements in the wavelength range 380-1040 nm.

The use of photo-stimulated luminescence (PSL) in dosimetry and dating applications is now well established, and a number of different stimulation sources are commonly used. These include the 514 nm argon-ion laser, infrared light emitting diodes, and broad band emitters such as incandescent or arc lamps in conjunction with carefully selected optical filters. Ideally however, the spectral emission and excitation characteristics of quartz and feldspar materials prepared for dosimetric evaluation should be routinely scanned, since this would also allow for the possibility of choosing the most suitable energy windows in which to carry out the measurements.

A compact module was developed and tested that allows for the monochromatic illumination of samples in the wavelength range 380-1040 nm, enabling the measurement of energy resolved optically stimulated luminescence. The design is based on the use of two different variable interference filters covering the spectral range of interest (the first usable in the range from 380 to 750 nm and the second from 740 to 1040 nm). The unit can be directly coupled to the existing automated Risø TL/PSL system, thus allowing for either routine scanning or more detailed thermo-optical investigations. The high throughput efficiency of the unit has shown that a 75 W tungsten-halogen lamp can be directly used as the light source for such measurements on both quartz and feldspar samples. The design allows for rapid spectral scanning with a choice of resolution of anywhere between 10 and 80 nm. Stray light levels are less than 0.01%. The unit (shown schematically in Figure 2.3) can equally well be used for recording wavelength-resolved emission spectra, whether photo excited or thermally stimulated.

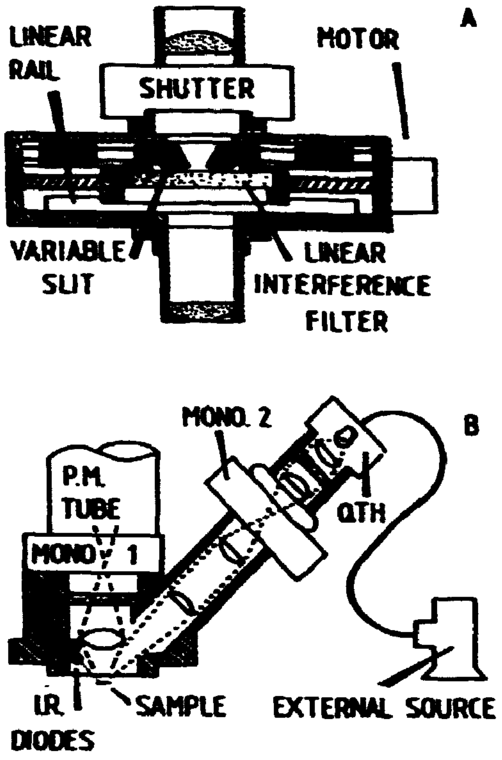


Figure 2.3. Detailed cross section of the Risø monochromator (a) and a schematic representation (b) of how it can be used on the TL/PSL apparatus in either detection (mono 1) or excitation (mono 2) mode.

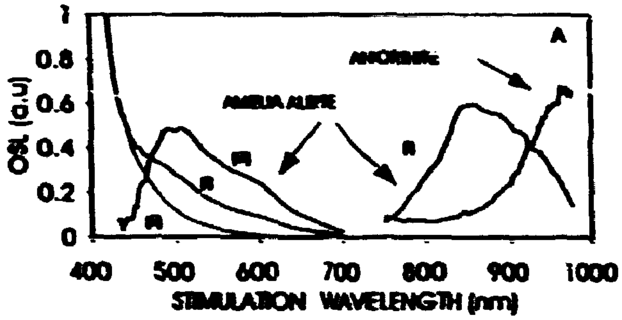


Figure 2.4. Optical stimulation spectrum (OSL vs stimulation wavelength) for a pure Amelia albite sample (curves (i), (ii) and (iii)) and an anorthite sample. Detection filter: U-340 (Beta dose: 60 Gy). The resonances of the Amelia albite at 500 and 600 nm are highlighted by curve (iii) which is the difference between the observed stimulation spectrum (curve (i)) and an approximation to the rising continuum (curve (ii)).

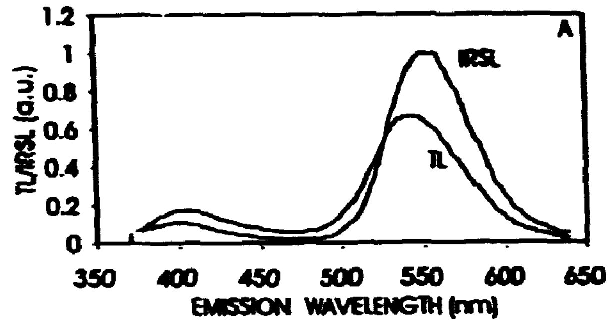


Figure 2.5. TL and IRSL emission spectra for an Amelia albite sample (TL: constant heating at 180°C. IRSL: excitation at 880 nm).

Excitation and emission spectrometry of photo-stimulated luminescence from quartz and feldspars.

The new scanning monochromator was designed to investigate the wavelength-resolved luminescence excitation and emission characteristics of quartz and feldspar samples. The unit was used to produce luminescence stimulation spectra by continuously scanning across the entire wavelength range from 400 to 1000 nm with detection using a U-340 filter (peak transmission at 340 nm).

Figure 2.4 shows the optical stimulation spectra obtained from natural albite and anorthite feldspars. The results obtained for the albite in the infrared range show the typical appearance of an infrared resonance at around 850 nm. In contrast, the infrared transition in anorthite shows a resonance shifted to higher wavelengths with an apparent peak at 970 nm. The stimulation spectrum obtained for the albite feldspar in the visible range showed a steeply rising continuum.

The thermally and optically stimulated luminescence emission spectra from different feldspar samples were also measured. The thermally stimulated (TL) and the infrared stimulated (IRSL) emission spectra from an albite feldspar sample are shown in Figure 2.5. It can be seen that the TL and IRSL emission spectra are very similar, implying that the same centres are involved in the two physical processes.

Development of a portable PSL system for the measurement of natural samples in the field.

As part of an EU research project a compact and lightweight computer-controlled system was developed that allows for the measurement of photo-stimulated luminescence of natural samples in the field, whether in the form of loose grains or compressed pellets. The unit uses infra-red excitation with highly efficient bleaching and PSL regeneration provided by cold-running gas discharge lamps.

The flexibility of the field instrument means that it can be simplified to a basic unit or extended to become a full luminescence spectrometer. Briefly, in the standard system luminescence excitation is provided by an array of infrared LEDs with photon counting detection using a blue sensitive photomultiplier tube. Sample bleaching is provided by a blue fluorescent lamp, and re- excitation of the PSL (for normalization) is via a low pressure Hg discharge tube. Up to 12 samples in the form of compressed pellets or loose grains on discs or cups are mounted into an interchangeable cartridge. A typical complete measurement cycle for 12 samples would take 30 minutes. The entire system fits into a small case and weighs only 5 kg. Since all components operate at 12 V, either portable or car batteries can be used as power sources.

2.2.2 Retrospective Dosimetry based on PSL Techniques

PSL techniques especially aiming at using natural materials to retrospectively reconstruct accidental radiation doses in populated areas were developed as part of an EU research project. Quartz and feldspar samples extracted from building materials, such as bricks and tiles, had their PSL signals measured to assess radiation doses received from the natural radionuclides embedded in the material in addition to the external photon radiation. Radiation doses were also evaluated from PSL measurements carried out on unseparated samples i.e. directly from the surface of the brick material.

PSL dosimetry of natural quartz extracted from bricks.

The accumulated »natural« dose induced in quartz by radionuclides contained in modern brick materials was measured using green light stimulated luminescence (GLSL) on extracted quartz samples. The aim of this experiment was to determine the lower detection limit for an additional dose received by a brick as a result of radioactive release from a nuclear accident, taking into account the GLSL contribution from the natural background dose. The brick was chosen from an outer wall of a laboratory building at Risø which was known to be about 40 years old. The quartz grains were extracted from the material and the absorbed dose was determined by GLSL using the additive dose technique. The evaluated dose appeared to be about 200 mGy which is in very good agreement with the expected value based on an annual dose rate of about 5 mGy/y from the natural radioactivity in the brick. For this particular brick a lower detection limit for an additional accidental dose would be of the order of 20 mGy (10% above the accumulated background dose).

Evaluation of depth dose profiles in bricks

Depth dose profiles in bricks irradiated in the laboratory were determined by measuring PSL on unseparated (mixed) materials directly from the surface of the bricks. Pieces from both modern and ancient bricks were annealed at 500°C to remove any previously acquired TL/PSL signal and then exposed to a dose of 5 Gy from Co-60 and Cs-137 photon radiation fields, respectively. After irradiation, cores of a diameter of 8 mm were cut out of each piece of brick and sliced into 1 mm thick circular discs using a diamond saw. Each disc, representing a particular depth in the brick, had their GLSL directly measured from the surface of the unseparated material. The depth dose profiles thus measured correspond reasonably well with the calculated profiles.

A similar measurement was made with a brick collected from a house in the town Berezyaki in the Chernobyl area. This dose profile shows a more rapid attenuation with depth as compared to that obtained from the Co-60 irradiation. This demonstrates that the Chernobyl brick was exposed to a gamma spectrum with a much higher content of low-energy photons.

2.2.3 Measurement of Environmental Photon Radiation

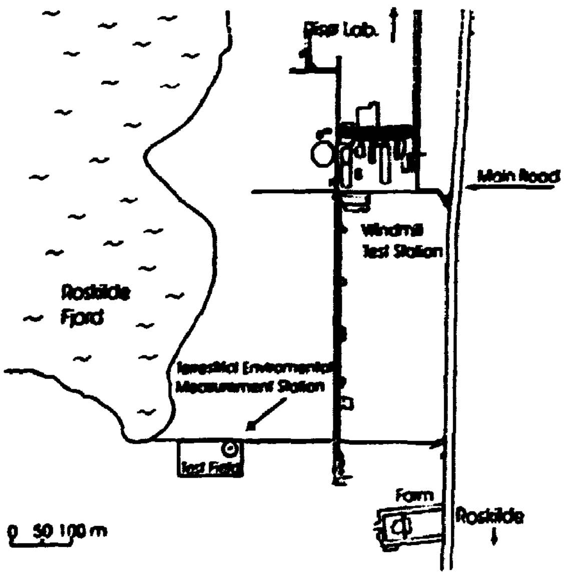
The Instruments and Methods Group co-ordinates an EU research project on environmental dosimetry. The aims of the project are to establish standard calibration procedures and to determine the responses of different active dose rate meters and passive solid state dosemeters to environmental photon radiation.

In connection with this project a natural radiation environment measurement station was established at Risø, thereby offering the EU member states a facility for reference measurements at a site with a well determined natural terrestrial photon spectrum. One important aspect of the measurement station is its capability to perform long-term comparative measurements with different detectors to e.g. analyze the contribution to the detector responses from radon daughters.

The test station was established at a site of 60 m × 100 m flat agricultural land inside the fence of the Risø National Laboratory. The test site is situated far from laboratory buildings, so the detectors to be tested there will be unaffected by the nuclear installations at Risø. It was considered important that the station could be established within the controlled area at Risø as a precaution against vandalism during long-term testing of expensive monitoring equipment. A situation plan of the test station is shown on the schematical map in Figure 2.6.

An instrument control hut made of wood was designed and built at the field site. The hut contains data loggers and controlling computers. Power lines, telephone and data net were installed which will permit the on-line transfer of data to any place in the world. Precipitation, air pressure and temperature gauges were installed and are continuously monitored by a computer. In addition to long-term measurements of the natural terrestrial radiation, the field site provides an excellent facility for carrying out free-field calibration experiments using low-active certificated gamma sources such as e.g. the nuclides Cs-137, Co-60 and Ra-226.

Figure 2.6. Situation map of the Risø Natural Radiation Environment Measurement Station.



2.2.4 Low Level Beta Multicounter Systems

A new beta multicounter system based on the gas-flow proportional counter concept was developed. Special integrated low-noise preamplifiers to be built directly into the individual counter elements were developed in collaboration with the Engineering and Computer Department at Risø. Materials with a low natural radionuclide content were selected for the construction of the compact counter with the aim of reducing the counter background to a minimum. The advantage of using proportional counters over GM counters in beta counting applications is the capability of being able to discriminate unwanted counting signals from contaminants in the beta samples. A measurement programme has been initiated to compare the features of the new proportional counter with the well established standard beta GM multicounter type.

2.3 Radon

2.3.1 Radon Research

The Risø Radon Test Structure

A new radon test structure has been established at a field site at Risø at a location near to the structure used in previous experiments. The main difference between the new and the old structure is that the new one is equipped with concrete footing and a concrete slab, thereby simulating a slab-on-grade foundation more closely. In addition, a larger number of probes have been installed in the soil below and around the new structure for mapping of pressure couplings and radon concentrations.

Figure 2.7 shows a cross-sectional view of the new quadratic test structure. The side length is 2.6 m and the footing extends approximately 0.75 m below the surface of the soil. A 40 litre cylinder (measuring chamber) is bolted to a steel plate that has been poured into the centre of the slab. Soil gas and radon enter the cylinder through a 9.5 cm hole in the bottom. A capillary breaking layer of highly permeable gravel is located below the slab. A shelter for instrumentation is located on top of the test-structure walls. A special subfloor is established a few centimetres below the top of the test structure walls. This subfloor consists of two PVC membranes of 0.5 and 1.5 mm in thickness placed on a base of wood. Access is provided to the substructure (i.e. the mini-basement) through an aluminium hatch.

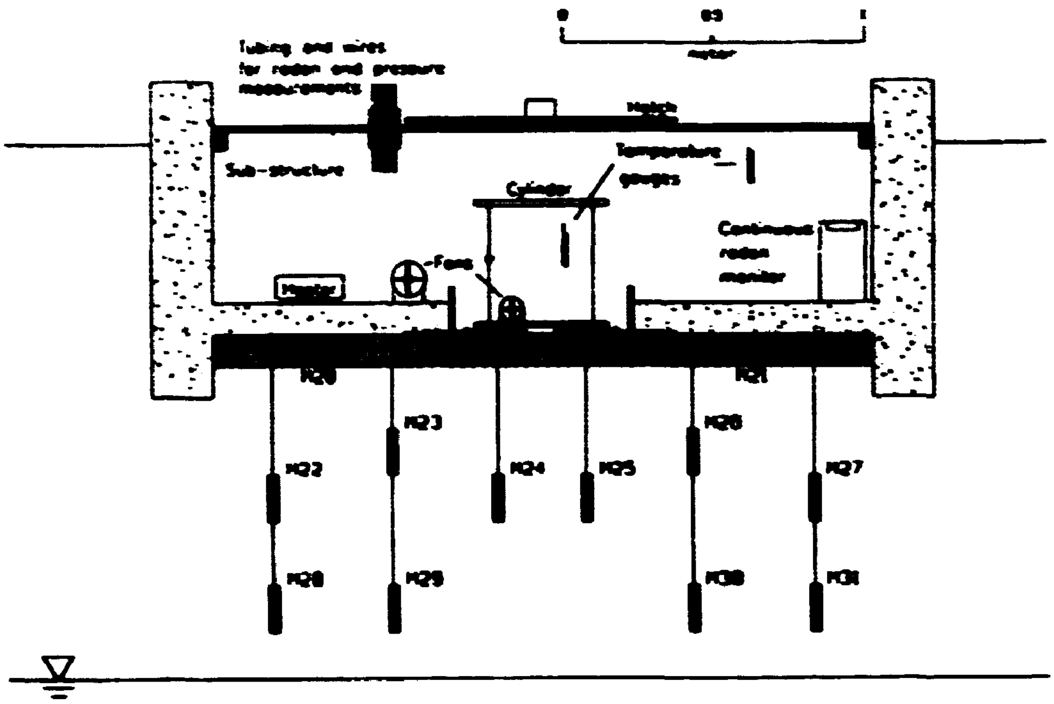


Figure 2.7. Cross-sectional view of the new test structure. Probes located below the slab are named M20 to M31.

The tight subfloor has made it possible to control that the concrete floor and walls are not permeable for soil-gas flow or radon diffusion.

During 1993, four long-term series of radon concentration measurements have been performed. In two of the series, a mass-flow controlled pump was set to draw air out of the cylinder at flow rates of approximately 5.5 and 20 l min^{-1}, respectively. In the two other series, the pump was turned off, and only natural driving forces operated. Under natural conditions, the radon concentrations ranged from above 100 $kBqm^{-3}$ for the probes at a depth of 1.5 m to 15 $kBqm^{-3}$ for the probes at a depth of 0.3 m. In the forced-flow experiments the soil was strongly depleted of radon.

The main outcome of the research conducted in the 1993-experiments is that the experimental results obtained at the new test structure are comparable to those obtained for the old one. The radon concentration fields are similar and the measured inverse flow resistances are comparable. When the ground water level is below 1.5 m, the inverse flow resistance for the new structure is 0.3 l $min^{-1}Pa^{-1}$ compared to 0.4 to 0.5 l $min^{-1}Pa^{-1}$ for the old one. This is interesting since measured permeabilities (measured within each of the two sites) range over several orders of magnitude. The experimental results obtained at the new test structure will help to validate numerical transport models and site characterization techniques.

Radon/VOC analogy

In 1993, the radon group was invited to prepare a contribution for a national meeting arranged by the Academy of the Technical Sciences on potential indoor and outdoor air quality problems for buildings located on sites contaminated with volatile organic compounds (VOC's) or other soil-gas pollutants. VOC's are of concern for private citizens and for various authorities due to the involved health risks. Methods are needed for site characterization and modelling of soil-gas transport in order to be able to estimate VOC entry rates into houses and to implement remedial actions. This is quite similar to the radon problem and the resemblance of the two fields should be utilised. The contribution from Risø focused on the similarities of combined diffusive and advective transport of VOC's and radon in soils. One practical consequence of these similarities is that the computational formalism used in a numerical transport model originally developed at Risø for radon-entry problems may also be applied to calculate the entry rate of volatile organic compounds. A series of model simulations conducted for a specific slab-on-grade house illustrated that the advective entry of VOC's may dominate the entry process for a number of situations typical for Danish houses.

EU project: Radon Sources, Models and Countermeasures.

During 1993, collaborations between Risø and other groups within the EU project named Radon Sources, Models and Countermeasures have been intensified. A Risø scientist spent 6 months at a postdoctoral stay at the Kernfysisch Versneller Instituut in the Netherlands, supported by the EU Human Capital and Mobility Programme. This work mainly concerned an analysis of diffusive and advective entry into a crawl-space house. Risø's numerical radon transport model was used in that study for system parameter identification. Risø's radon transport model is also used in an ongoing collaboration with the Swedish Radiation Protection Institute in Stockholm to study radon entry into one of their experimental houses.

2.3.2 Instrumentation

A general update of radon instrumentation and calibration facilities at Risø was initiated in 1993. A test version of a multicounter for automatic handling of 12 scintillation cells has been designed and tested. Furthermore it is planned that the instrumentation shall include a reference instrument (based on electric field precipitation of radon daughters on a surface-barrier detector located in a 1 litre glass sphere) and a standard radon-222 source from the National Institute of Standards and Technology, USA.

2.3.3 Radon Measurements in Homes

During 1993, 3-month radon measurements have been made on a commercial basis in 60 private homes. The measurements were carried out with track detectors in the spring and autumn seasons, where the 3-month results are likely to be close to annual-average values. The results are included in our data bases on measured radon concentrations in Danish houses.

2.4 Emergency Preparedness

The Nationwide Nuclear Emergency Preparedness Plan issued by the Emergency Management Agency (EMA) came into operation on April 1, 1993. The EMA's Emergency Co-ordination Centre was enlarged and it has taken over some of the responsibilities of the Technical Emergency Response Centre (TBT) at Risø. TBT is still obliged to organize measuring teams and to assist with other tasks after agreement with the central Emergency Co-ordination Centre. As a consequence of these changes all directives and instructions dealing with TBT have been revised.

The National Radiation Monitoring Network consists of 11 measurement stations across the country. Since December 1989 radiation measurements at the stations have been collected every hour by a computer at Risø and retransmitted to a computer at the EMA. The data collection at Risø has been working satisfactorily but the retransmission to EMA has frequently been cut off. During February and March 1993 the stations were updated so that both the Risø computer and the EMA computer are now able to collect data directly from the stations. This has increased the reliability of the system.

On May 13 the radiation monitoring station at Herning gave alarm due to high readings from both the ionization chamber and the NaI-crystal detector. 50 - 60 metres from the station the weldings on some district heating pipes were controlled by means of an Iridium-194 source, which caused the alarm. This incident confirmed the sensitivity of the monitoring stations.

Under the Nordic Nuclear Safety Research Programme 1990-1993, the Health Physics Section was entrusted with the management of the BER-3 project entitled: Evaluation and Harmonization of the Planning of Countermeasures and the Use of Intervention Levels. In order to investigate the Danes' »willingness-to-pay« for an extra year of life, a pilot-study was performed in January 1993 by the Vilstrup Research Institute in Copenhagen. The study was based on two small interview series by visits and by telephone. The result was an average »willingness to pay« of between 60 000 and 70 000 DKK for an extra year of life. This is a low value compared with the results of similar investigations in other countries.

Two Nordic exercises NORA and ODIN were organised by the BER-5 project under the same Nordic programme with the aim of improving Nordic emergency preparedness cooperation. The Health Physics Section was responsible for setting up the scenarios in both exercises.

2.5 Publications

2.5.1 Publications in International Journals, Proceedings and Reports

Andersen, C.E.; Søgaard-Hansen, J.; Damkjær, A.; Majborn, B., Modellering og måling af radons indtrængning i bygninger - analoger til indtrængning af andre gasser. In: Vurdering af inde- og udeklima på grunde forurenet med flygtige organiske kemikalier. ATV møde, København (DK), 4 Nov 1993. (ATV-komiteen vedrørende grundvandsforurening. Instituttet for Geologi og Geoteknik, Lyngby, 1993) p. 133-150.

Bøtter-Jensen, L.; Jungner, H.; Mejdahl, V., Recent developments of OSL techniques for dating quartz and feldspars. Radiat. Prot. Dosim. (1993) v. 47 p. 643-648.

Bøtter-Jensen, L.; Lauterbach, U.; Delgado Martinez, A., The Measurement of environmental gamma doses. In: Commission of the European Communities. Radiation protection programme. Progress report 1990-91. EUR-14927 (1993) p. 113-127.

Christensen, P., Study of LiF:Mg,Cu,P TL detectors for individual monitoring for weakly penetrating radiations, Radiat. Prot. Dosim. (1993) v. 47 p. 425-430.

Christensen, P.; Chartier, J.L.; Herbaut, Y.; Francis, T.M., Dosimetry of beta and low-energy photon radiation using extrapolation chambers and thin solid state dosimeters. In: Commission of the European Communities. Radiation protection programme. Progress report 1990-91. EUR-14927 (1993) p. 129-141.

Duller, G.A.T.; Bøtter-Jensen, L., Luminescence from potassium feldspars stimulated by infrared and green light. Radiat. Prot. Dosim. (1993) v. 47 p. 683-688.

Gómez Ros, J.M.; Muniz, J.L.; Delgado, A.; Bøtter-Jensen, L.; Jørgensen, F., A glow curve analysis method for non-linear heating hot gas readers. Radiat. Prot. Dosim. (1993) v. 47 p. 483-487.

Julius, H.W.; Christensen, P.; Marshall, T.O., New European technical recommendations for individual monitoring. In: Intercomparison of radiation dosimeters for individual monitoring. Final report of a co-ordinated research programme 1988-1992. IAEA-TECDOC-704 (1993) p. 79-85.

O'Riordan, M.C., Meijer, R.J. De; Damkjaer, A.; Majborn, B.; Mets, G. De; Jong, P. De; Ball, K.; Enflo, A.; Proukakis, P., Radon sources and models (NRPB Association). In: Commission of the European Communities. Radiation protection programme. Progress report 1990-91. EUR-14927 (1993) p. 1089-1107.

Prokic, M.; Bøtter-Jensen, L., Comparison of main thermoluminescent properties of some TL dosemeters. Radiat. Prot. Dosim. (1993) v. 47 p. 195-199.

2.5.2 Risø Reports

Aarkrog, A.; Hansen, H.; Bøtter-Jensen, L.; Nielsen, S.P.; Clausen, J., Radioactivity in the Risø district July - December 1992. (Radioaktiviteten i Risøområdet juli - december 1992). Risø-I-715(EN) (1993) 22 p.

Aarkrog, A.; Hansen, H.; Bøtter-Jensen, L.; Nielsen, S.P.; Clausen, J., Radioactivity in the Risø district January - June 1993. (Radioaktiviteten i Risøområdet januar - juli 1993). Risø- I-751(EN) (1993) 22 p.

Andersen, C.E.; Søgaard-Hansen, J.; Majborn, B., Soil-gas and radon entry into a simple test structure: Comparison of experimental and modelling results. Workshop contribution and additional Figures. Risø-I-716(EN) (1993) 19 p.

Bluszcz, A.; Bøtter-Jensen, L., Calibration of a beta source using TL and OSL on quartz. Risø-I-725(EN) (1993) 22 p.

French, S.; Walmod-Larsen, O.; Sinkko, K., Decision conferencing on countermeasures after a large nuclear accident. Report of an exercise by the BER-3 of the NKS BER programme. Risø-R-676(EN) (1993) 24 p.

Majborn, B.; Brodersen, K.; Højerup, C.F.; Heikel Vinther, F. (eds.), Nuclear Safety Research Department annual progress report 1992. Risø-R-679(EN) (1993) 29 p.

Yamamoto Hideaki; Nielsen, S.P.; Nielsen, F., Predicted effects of countermeasures on radiation doses from contaminated food. Risø-R-665(EN) (1993) 31 p.

2.5.3 Other Publications

Brøns, P.; Hansen, H; Andersen, E., Vor radioaktive klode 7. Strålingsbiologi - grundlæggende mekanismer. Nat. Verden (1993) (no.6) p. 233-248.

Brøns, P.; Hansen, H; Andersen, E., Vor radioaktive klode 8. Strålingsbiologi - Hvad er så risikoen?. Nat. Verden (1993) (no.7) p. 273-280.

Brøns, P.; Hansen, H; Andersen, E., Vor radioaktive klode. (Rhodos, København, 1993) 84 p.

2.6 Lectures at Conferences and Meetings

Andersen, C.E., Modelling of radon transport in soil; comparison with results of the test structure experiment at Risø. Kollokvium: Werkbespreking onderzoehsgroep Radioactiviteit in Woon - en Leefmilieu. Kernfysisch Versneller Instituut, Groningen (NL), 18 Mar 1993. Unpublished.

Andersen, C.E., Modelling and measurement of radon entry: Test structure experiments and real house simulations. SSI-Kollokvium, Stockholm (SE), 21 Oct 1993. Unpublished.

Bøtter-Jensen, L.; Poolton, N.J.R.; Duller, G.A.T., Excitation and emission characteristics of optically stimulated luminescence in feldspars and quartz. 7. International specialist seminar on thermoluminescence and electron spin resonance, Krems (AT), 5-9 Jul 1993. Unpublished. Abstract available.

Bøtter Jensen, L.; Poolton, N.R.J., A compact design for monochromatic OSL measurements in the wavelength range 380-1020 nm. 7. International specialist seminar on thermoluminescence and electron spin resonance, Krems (AT), 5-9 Jul 1993. Unpublished. Abstract available.

Christensen, P.; Griffith, R.V., Required accuracy and dose thresholds in individual monitoring. Workshop on individual monitoring of ionizing radiation: The impact of recent ICRP and ICRU publications. Paul Scherrer Institute, Villigen (CH), 5-7 May 1993. Unpublished. Abstract available.

Julius, H.W.; Marshall, T.O.; Christensen, P.; Dijk, J.W.E. van, Type testing of personal dosemeter for photon-energy and angular response. Workshop on individual monitoring of ionizing radiation: The impact of recent ICRP and ICRU publications. Paul Scherrer Institute, Villigen (CH), 5-7 May 1993. Unpublished. Abstract available.

Jungner, H.; Bøtter-Jensen, L., Study of sensitivity change of OSL signals from quartz and feldspars. 7. International specialist seminar on thermoluminescence and electron spin resonance, Krems (AT), 5-9 Jul 1993. Unpublished. Abstract available.

Mejdahl, V.; Bøtter-Jensen, L., OSL dating of quartz and feldspars from archaelogical materials. 7. International specialist seminar on thermoluminescence and electron spin resonance, Krems (AT), 5-9 Jul 1993. Unpublished. Abstract available.

Poolton, N.R.J.; Bøtter-Jensen, L.; Ypma, P., The influence of crystal structure on the excitation and emission spectra of OSL in alkali and plagioclase feldspars. 7. International specialist seminar on thermoluminescence and electron spin resonance, Krems (AT), 5-9 Jul 1993. Unpublished. Abstract available.

Poolton, N.R.J.; Bøtter-Jensen, L.; Hvidtfeldt Christiansen, H.; Wintle, A.G., A portable OSL system for measurement of luminescence spectra of sediments in the field. 7. International specialist seminar on thermoluminescence and electron spin resonance, Krems (AT), 5-9 Jul 1993. Unpublished. Abstract available.

Walmod-Larsen, O., Project Crested Ice, Greenland 1968. International symposium on remediation and restoration of radioactive-contaminated sites in Europe, Antwerp (BE), 11-15 Oct 1993. Unpublished. Abstract available.

3 Reactor Physics

Work in the Reactor Physics Section falls mainly in the three categories

1) Reactor Physics
2) Reactor Safety
3) Activities at the DR 1 reactor

3.1 Reactor Physics

Reactor physics is the discipline concerned with the nuclear processes in reactor cores and as such fundamental for the understanding of both operation and safety aspects of nuclear reactors.

Specific problems dealt with in 1993 are:

- The development of collision probability routines for elementary cells of LWRs and their implementation in an interface current flux routine (3.1.1).
- Participation in some international benchmarks, one to test the ability of the programmes to predict the power distribution in assemblies loaded with strongly absorbing MOX fuels and another to assess the quality of prolonged burn-up predictions (3.1.2).
- Calculations of the radioactivity of some construction elements of the Swedish Ringhals 2 pressurized water reactor (3.1.3).
- Assistance to the operation of the DR 3 reactor (3.1.4).
- Calculations for the support of the comprehensive production of neutron-transmuted silicon crystals which takes place in DR 3 (3.1.5).
- Calculation of the nuclear inventory in the Ignalina Nuclear Power Plant (3.1.6).

3.1.1 Nodal Collision Probability Theory

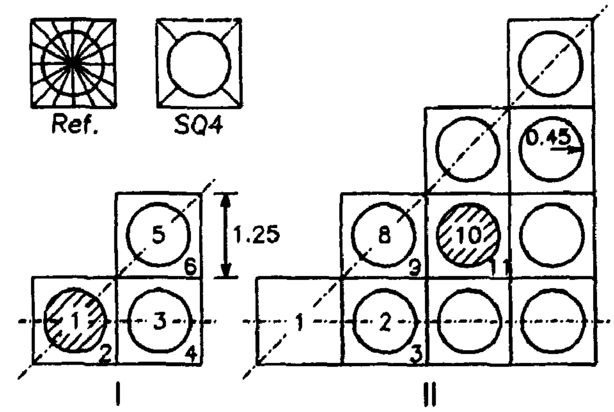
The development of a multigroup LWR fuel assembly code, named NICOLAS, is in progress. The neutron flux distribution within each energy group is based on the flat-flux, isotropic collision probability method for the cell calculations combined with the interface-current method providing the coupling between cells.

Fuel pin subroutines for calculating the collision, escape, and transmission probabilities related to cylinderized cells or square cells with optional diagonal subdivision of the outer moderator volume into four segments are presently available. Further cell types are contemplated for representation of BWR water gaps, etc. The numerical integration technique employed for the square cells is a 2-D extension of the well-known »Flurig« scheme with Gaussian quadrature in both the radial and the angular direction, which has proved significantly more efficient than commonly applied methods. The approximations of the model were investigated by comparison with published results for two benchmark cases (see Figure 3.1.1). These investigations included the assumed cosine-current distribution on the cell surfaces relative to perfect angular resolution, and the simpler segmentation (SQ4) relative to the refined reference cell partitioning. Taking the additional effects of anisotropic scattering and sources into account, the accuracy in absolute terms is estimated to be within two per cent for the fluxes in the fuel regions. Further details are given in an article prepared for publication.

The systems considered may range from a single cell to several fuel assemblies. The most commonly occurring symmetries for single assemblies and systems of four assemblies (checkerboard and colour-set patterns) with odd and even cell numbers can be handled. Either reflective or cyclic boundary conditions may be specified.

Before programming, the original first-flight probability equations were preconditioned by traditional Gaussian elimination of the region fluxes, cell by cell, resulting in a set of nodal equations with the interface currents as the nodal

Figure 3.1.1. Lattice benchmark problems I and II with burnable absorber pins (hatched) and a central water hole in case II. Reference and SQ4 cell partitioning shown.



variables, which are solved iteratively. Upon convergence, the fluxes are calculated directly, using the converged currents. Various acceleration techniques, including successive overrelaxation and current normalization at each iteration stage, have been implemented. The basic theory and investigations of the convergence rate improvements obtained by these methods are the subjects of another article in preparation.

3.1.2 Participation in International Benchmark Exercises

The Nuclear Science Committee of the OECD organizes comparisons of computer code performance.

The Reactor Physics Section has participated in two such benchmarks:

In the benchmark on »Calculations of Power Distributions within Assemblies«, the nodal expansion method code NEM2D was used to calculate the flux/power distributions in 6 different reactor configurations, made up by assemblies containing UO_2-pins, PuO_2-pins, empty (water filled) pins, and absorber pins. The agreement between the results of the participants was very good (including our results).

The benchmark »Burn Up Credit Criticality« concerns the prediction of the production/destruction of actinides and fission products during long burn-up periods. The background for running the benchmark was to obtain an overview of the theoretical predictions of burn-up calculations in order to safely allow larger shipments of spent fuel assemblies which are presently treated as new assemblies when criticality considerations are made. The outcome of the benchmark is presently being evaluated.

3.1.3 Ringhals Calculations

Calculations similar to the ones reported last year for the Ringhals 1 BWR have been performed for the PWRs of the Ringhals station (Ringhals 2, 3, and 4 are Westinghouse PWRs).

The calculations were made to estimate the neutron induced activations of various reactor tank internals, situated above and beneath the core.

When trying to extend the calculations to include items situated very far from the core (the top lid, and the bolts securing the top lid) it was discovered that the model used was very inaccurate, as neutrons leaking from the reactor tank at core level would contribute substantially, by streaming outside the tank, to the neutron intensity at the remote sites.

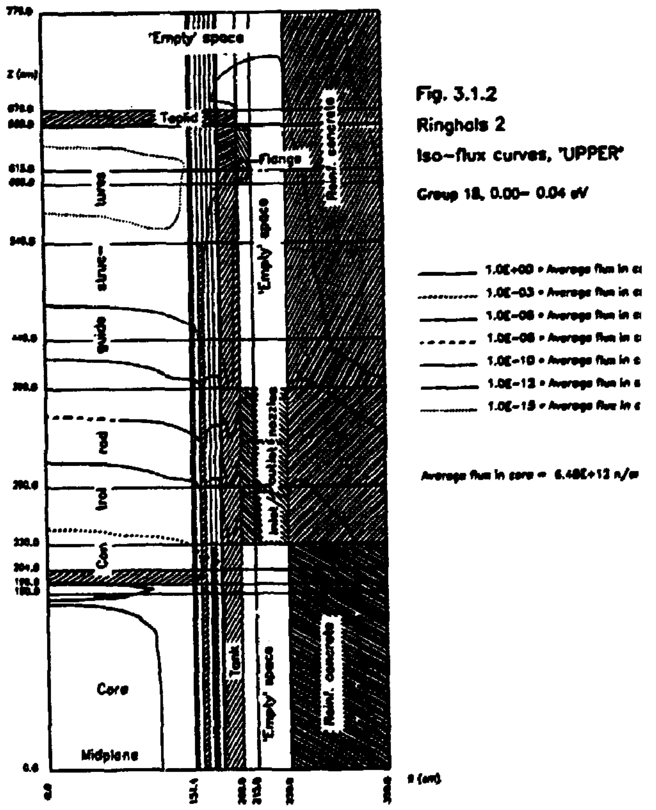
Various approaches were tried to come around the problem which is unsolvable in the frame of the codes available (diffusion theory codes). By some adjustments of the diffusion properties of the thermal insulation layer surrounding the reactor tank, it was possible to obtain a reasonable agreement with two existing measurements of the Co-60 activities of samples of bolt material and of top lid liner material.

An example of the extreme variation of the neutron intensity which is being dealt with is shown in Figure 3.1.2. The »isoflux« curves of the group of neutrons with the lowest energy are shown. Also, the rather complicated geometry of the reactor and its surroundings appears from the figure.

3.1.4 DR3 Reactor Physics

The computer code DR3SIM, applied by the operating staff at the reactor DR3, has been modified during 1993 on demand from the user. Thus

Figure 3.1.2. Iso-flux curves of the group of neutrons with the lowest energy in the upper part of a Ringhals PWR.



a more user-friendly input and output interface has been implemented and some minor errors corrected.

However, the code has not been able to simulate a reduced reactivity value of the two safety control rods in DR3 measured by the operating staff. Apparently the applied model of the two safety rods in the computer code is insufficient. A calculation with a similar code at Argonne National Laboratory will be carried out in 1994 to verify whether a modification of the simulator DR3SIM is necessary.

3.1.5 Silicon Irradiation

At Risø's research reactor DR3 a horizontal facility for nuclear transmutation of silicon is operated. In this process a silicon crystal is irradiated while it is moved slowly from one side of the reactor to the other to obtain a uniform irradiation. Sometimes a crystal gets stuck in the horizontal irradiation tube and receives a non-uniform irradiation profile. A computer program developed last year to simulate the course of a failed crystal has again been succesfully applied to calculate a procedure by which a stuck crystal was re-irradiated to fulfil the specifications.

3.1.6 Ignalina Calculations

On request from the Danish Emergency Management Agency a calculation has been made of the total nuclear inventory in one of the RBMK reactors at the Ignalina nuclear power plant in Lithuania. For that purpose a computer code called CCCMO has been applied assuming an average burnup of the fuel of about 15.000 MWd/tU.

A comparison of important design differences between the Ignalina and Chernobyl reators has also been made.

The project is carried out in co-operation with the Health Physics Section, the Ecology Section and the Meteorology Section, and it includes calculations of doses in Denmark for different postulated accident scenarios at the Ignalina nuclear power plant.

3.2 Reactor Safety

The work consists of

- Studies of hydrogen deflagration in containments under accident conditions (3.2.1).
- Participation in the EU »Source Term« project (3.2.2).
- Participation in the SIK projects within the Nordic Nuclear Safety Research Programme (NKS):
- SIK-2, which addresses »Severe Accidents« (3.2.3).
- SIK-3, where safety-related data for reactors in neighbouring countries are collected (3.2.4).
- Participation in the work of the Risø Study Group for Nuclear Preparedness (3.2.5).

3.2.1 Hydrogen Deflagration

A model for simulating the combustion of hydrogen with nonsimultaneous multipoint ignition, considering the spatial nonuniform distribution of the components of the atmosphere, has been implemented in the computer program CONTAIN 1.12. For this, the nodalization scheme of the code has been refined in an array of user-defined subcells for which the geometrical characteristics, atmospheric composition, number of ignitors, and ignition criteria are specified. Some calculations have been performed for the constant-volume combustion experiments with simultaneous multiple ignition of dry H_2-air mixtures performed at the intermediate-scale Containment Test Facility at Whiteshell Laboratory in Canada.

The research activities related to this project have been completed. The main results have been included in the thesis »Hydrogen Problems Related to Reactor Accidents« published as Risø-R-706(EN).

3.2.2 Containment Modelling

The coupling between thermal hydraulics and aerosol physics has for practical reasons (computer limitations) often been treated as a one-way coupling from thermal hydraulics to aerosol physics. However, physical considerations suggest and experiments show that a feed-back from aerosol physics to thermal hydraulics can be important for some reactor accident sequences. In the CEC-initiated Reinforced Concerted Action Source Term project, one task is to investigate this mutual coupling. During the first year, a state-of-the-art report on experiments, models, computer codes, and calculations has been produced in this collaboration.

3.2.3 SIK-2

SIK-2.6, Assessment of Aercsol Modelling, is a task in the Nordic SIK-2 project on Nuclear Reactor Accident Analysis, performed to verify that the aerosol models (important for calculation of a hypothetical release) are state-of-the-art.

The codes considered for the reactor coolant system are RAFT, TRAP-MELT3, SCDAP/RELAP5, VICTORIA, MELCOR, and MAAP. These codes have different areas of application, ranging from detailed analysis of laboratory experiments to parametric studies of severe accident sequences, in which the aerosol modelling must necessarily be simplified because of computing time. In the investigation, the various models applied in the codes were assessed and even a few trivial errors revealed. The work on containment codes is in progress.

3.2.4 SIK-3, Safety Related Data for Neighbour Reactors

The objective of the SIK-3 project is to collect, systematize, and evaluate safety related data of nuclear installations within and close to the Nordic countries. The data include design features and operational practices significant for the plant safety. The data collected and the expertise gained in the project have two main applications:

- Based on the data, the safety authorities can respond to general safety-related questions concerning a particular design.Such questions can come from politicians, the public, or the media.
- In case of an emergency situation at a plant located in a neighbouring country, the data can help the Nordic safety authorities to assess the severity and course of the accident, potential external consequences and necessary emergency response actions.

The data are presented in reports of about 100 pages for each nuclear power plant.

The four-years project has now been finished and reports have been made on the nuclear power plants shown in Table 3.2.4.

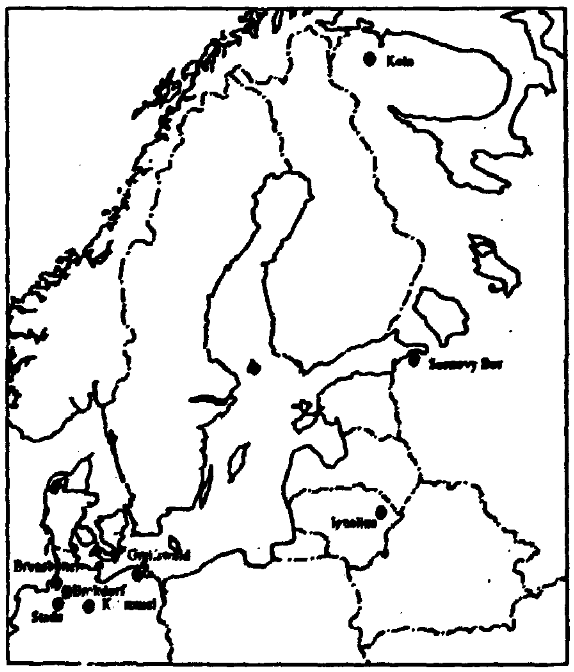
Figure 3.2.4 shows the corresponding locations of neighbouring nuclear power plants treated in the SIK-3 project.

Table 3.2.4. Reactors within 500 km from the borders of the Nordic countries

Nuclear Power Plant	Reactor Type	No. of Units	Distance
Greifswald	VVER	6	80 km (DK)
Leningrad	RBMK	4	100 km (SF)
Ignalina	RBMK	2	450 km (S)
Kola	VVER	4	120 km (SF)
Brunsbüttel	BWR	1	100 km(DK)
Krümmel	BWR	1	200 km (DK)
Brokdorf	PWR	1	100 km (DK)
Stade	PWR	1	150 km (DK)
Marine reactors	(PWR)		

The outcome of the project has been an increased level of information about the design features of especially the Russian reactor types. The project has also created a contact net between the managers of the Kola, Ignalina, and Sosnovy Bor nuclear power plants, and the Nordic safety authorities, which could be useful in the case of an accident. Finally, the reports have been utilized by Western companies and institutions in their bilateral assistance programmes to the Eastern countries.

Figure 3.2.4. Locations of the nuclear power plants treated in the SIK-3 project.



3.2.5 Safety of Advanced Reactors

The work in the nuclear preparedness group has dealt with special problems related to the safety of advanced reactors.

A Master's thesis study was conducted examining possible ways of reducing the positive void coefficient of fast sodium-cooled reactors. The concept of introducing a material with nuclear properties which would counteract the positive reactivity effect of the spectral hardening accompanying a voiding of the sodium was examined. It was found that it is not possible to obtain a sufficient effect by this method.

3.3 Activities at the DR1 Reactor

Activities at the DR1 reactor have comprised

- Courses on experimental reactor physics for high-school classes and students (3.3.1).
- Irradiation of computer memories with fast neutrons to examine bit error frequencies (3.3.2).

3.3.1 Education

The reactor has been used almost exclusively for educational purposes. 50 high-school classes have carried out one day or half-a-day experiments at the reactor. The total number of students in 1993 was more than 900.

A number of students from the Technical University of Denmark have carried out experiments at the reactor over a period of three weeks.

Some of the experiments were:

- Determination of the reactor's temperature-, power-, and bubble-coefficients
- Neutron activation analysis
- Measurements of neutron cross sections
- Neutron radiography
- Health physics experiments
- Core flux distribution measurements.

3.3.2 Neutron-Induced Bit Errors in Computer Memories

In 1991, a Danish software firm experienced problems with bit errors (Single Event Upsets or SEUs) in small computers used on long-distance passenger flights.

The characteristics of the error patterns were readily reproduced by exposure to a neutron source available at DR1, whereas conventional causes (vibrations, extreme temperatures etc.) were ruled out by tests performed by the manufacturer.

Fast neutrons are produced at flight altitudes when cosmic ray particles (mainly protons) hit oxygen or nitrogen nuclei. When the fast neutrons in turn hit silicon nuclei, recoils and in some cases protons or alpha particles are produced. The ionization generated by the recoiling nuclei causes the majority of the SEUs.

During 1993 tests were performed on various CMOS,SRAM's for an electronics company. The tests showed that one of the CMOS,SRAM's was remarkably resistant to SEUs. According to the manufacturer of the chips, they were not especially hardened and the reason for their resistance is still unclear.

3.4 Publications

3.4.1 Publications in International Journals, Proceedings and Reports

Olsen, J.; Becher, P.E.; Fynbo, P.B.; Raaby, P.; Schultz, J., Neutron-induced single event upsets in static RAMS observed at 10 KM flight altitude. IEEE Trans. Nucl. Sci. (1993) v. 40 (no.2) p. 74-77.

3.4.2 Risø Reports

Bujor, A., Hydrogen problems related to reactor accidents. Risø-R-706(EN) (1993) 79 p.

Bujor, A., A model for multipoint ignition of H2 in containment. Risø-I-707 (1993) 43 p.

Fynbo, P.B., Aerosol modelling in severe accident codes. 1. Reactor coolant system codes. Risø-I-671 (1993) 43 p.

Hjerrild Nielsen, K.; Nonbøl, E., Possible ways of reducing the sodium void coefficient in fast reactors. Risø-I-706 (1993) 10 p.

Højerup, C.F., Calculation of neutron induced activation of construction elements in Ringhals 2. Risø-I-710 (1993) 86 p.

Højerup, C.F., TOPNUX. Towards the next generation of light water reactors. Risø-I-747 (1993) 11 p.

Højerup, C.F., XENON oscillations. With special reference to the PIUS reactor. Risø-I-750 (1993) 33 p.

Lauridsen, K.; Kongsø, H.E.; Becher, P.E.; Petersen, K.E., Reliability assessment of the TELEMAN-machine. Failure strategy. Risø-Dok-274 (1993) vp.

Lauridsen, K.; Nonbøl, E.; Paulsen, J.L., BVT. Simuleringsmodel af en Barsebäck enhed. Risø-I-685(DA) (1993) 36 p.

Majborn, B.; Brodersen, K.; Højerup, C.F.; Heikel Vinther, F. (eds.), Nuclear Safety Research Department annual progress report 1992. Risø-R-679(EN) (1993) 29 p.

Thomsen, K.L., Nodal interface-current, collision-probability methods. Risø-I-752 (1993) 18 p.

3.4.3 Other Publications

Fynbo, P.B., Kosmisk stråling kan give fejl i flycomputere. Risønyt (1993) (no.2) p. 6-7.

3.5 Lectures at Conferences and Meetings

Højerup, C.F., Xe-svingninger i PIUS-reaktoren. Videnberedskabs seminar, Roskilde (DK), 18 March 1993. Unpublished. Abstract available.

Højerup, C.F., Neutron Cross Section Libraries Used at Risø. Reactor Physics Calculations in the Nordic Contries, Roskilde (DK), 5-6 May 1993. Unpublished. Abstract available.

Højerup, C.F., XENON Oscillations. With Special Reference to the PIUS Reactor. Reactor Physics Calculations in the Nordic Contries, Roskilde (DK), 5-6 May 1993. Unpublished. Abstract available.

Højerup, C.F., TOPNUX. Towards the Next Generation of Light Water Reactors. Videnberedskabs seminar, Roskilde (DK), 16 Nov. 1993. Unpublished. Abstract available.

Koroll, G.W.; Bowles, E.M.; Bujor, A., Hydrogen Combustion with Simultaneous Multiple Ignition. I.P.S.N. - C.O.G. Hydrogen Working Group Meeting, Fontenay Aux Roses (FR), 20-22 Sept. 1993. Unpublished. Abstract available.

Koroll, G.W.; Bowles, E.M.; Bujor, A., Hydrogen Combustion with Simultaneous Multiple Ignition. 2nd German-Canadian Workshop on Hydrogen, Pinawa, Canada, 20-22 Oct. 1993. Unpublished. Abstract available.

Nonbøl, E., Studiebesøg på Ignalina-værket i Litauen. Videnberedskabs seminar, Roskilde (DK), 18 March 1993. Unpublished. Abstract available.

Nonbøl, E., Possible Ways of Reducing the Sodium Void Coefficient in Fast Reactors. Reactor Physics Calculations in the Nordic Contries, Roskilde (DK), 5-6 May 1993. Unpublished. Abstract available.

Thomsen, K.L., Nodal Interface-Current, Collision-Probability Methods. Reactor Physics Calculations in the Nordic Contries, Roskilde (DK), 5-6 May 1993. Unpublished. Abstract available.

4 Waste Management

The Waste Management Section at Risø takes care of handling and storage of radioactive waste from all Danish users of radioisotopes. Most of the waste comes from the nuclear installations at Risø but about a third of the waste is coming from outside, primarily from hospitals, industry and various laboratories.

The waste can only be stored temporarily at Risø and will have to be disposed of some time in the future. Disposal is not expected to take place before well into the next century, but it is important to keep in contact with the international development within the field. The Waste Management Section is therefore participating in international research concerned with the safety of disposal systems. Work is done within Nordic cooperative projects and in connection with the EU research programme on radioactive waste management. Participation in the EU advisory commitee on practical waste management is also valuable for maintaining good relationships with persons responsible for radioactive waste management in other countries.

4.1 Practical Waste Management

The treatment plants for radioactive waste were operated as usual. They consist of a recently renovated balling press for compaction of low-level solid waste, a distillation plant based on the steam recompression principle for purification of radioactive waste water,and a final evaporator for the bituminization of the resulting evaporator concentrates. The inactive waste-water treatment plant, the collection of chemically toxic waste,and the decontamination and laundry facilities were also operated as usual.

The total release of mixed ß-emitters with the purified waste water was ~177 MBq. This is about 1.2 % of the permitted release to Roskilde Fiord. In addition 2810 GBq of tritiated water was released with the distilled water, and about 7 GBq ^{14}C-carbon-dioxide was released to the atmosphere with off-gas from the bituminization plant.

A considerable amount of unconditioned α-contaminated waste from the decommissioning of the Hot Cell laboratory was also recieved and stored in 1993. The decommissioning period was extended to medio 1994, but the amount of waste from this last period is not expected to be large.

The normal radioactive waste treatment procedures resulted in a total of 131 drums containing bituminized evaporator concentrate or compacted low-level solid waste.

The storage building for low-level waste near the Waste Management Plant is now used routinely for storage of the running production of low-level waste drums. In the spring 503 drums from the newest part of the old storage facility (Betonrørslageret) were transfered to the new building. This could be done rapidly because the conditions of the drums in general were satisfactory. The removal of the drums resulted in a considerable reduction of the radiation level at the fench around the area.

During the later part of the year 129 drums from the older part of the storage facility were moved to the new building. This proved to be more complicated and time consuming than expected, mainly because about half of the drums had to be reconditioned due to various types of corrosion damages developed during the 20-30 years of storage in the old facility. Documentation of the types of damages and ideas about the mechanisms which may be responsible are collected.

Reconditioning is done by placing the corroded older units inside a polyethylene bag in a new 280 l steel drum and filling the annular space with cement mortar.

External γ-measurements of radioisotopes are made on all drums placed in the new storage building. Information on the contents of ^{137}Cs and ^{60}Co are obtained but with considerable uncertainties.

Permission for external disposal as inactive material of the very weakly radioactive-contaminated sludge from the biological waste water purification plant at Risø has still not been received from the Nuclear Authorities.

4.2 Waste Materials Research

Radioactive waste management and radioactive waste disposal require knowledge about the long-term behaviour of the various waste materials under different storage and disposal conditions.

Experience from the above-mentioned transfer of old waste units from one storage facility to another shows that such knowledge is important for the practical management of waste in temporary storage. For safety assessments of disposal systems similar information may have to be extrapolated over very long time spans. Long-term experiments and/or experiments designed to elucidate fundamental aspects of the chemistry and physics of the waste products and their interaction with the environment are therefore characteristic for waste materials research.

4.2.1 Properties of Bituminized Materials

Studies under the four-year CEC contract on »Characteristics of Bituminized Waste« was continued as a cooperative project between CEN Cadarache, France, CEN/SCK Mol, Belgium, and Risø. The second annual report 1993 is in preparation.

The experiments done at Risø are of three different types: Diffusivites of tritiated water and ions in thin bitumen layers are measured using membrane techniques. Leaching, water uptake and swelling of bituminized materials containing soluble salts are determined as functions of time by a combination of chemical analyses and weighings of the samples in air and suspended in water. Results from one experiment is shown in Figure 4.2.1. The internal pressurization of confined samples by water uptake through barriers of porous cement mortar is also followed. The three experimental techniques were all developed at Risø in connection with previous EU contracts.

The results are in agreement with previous experiments with synthetic waste products. So far it has unfortunately not been possible to determine why the rate of water uptake and swelling is often much higher in real waste products.

A model describing the swelling and leaching behaviour of bituminized materials containing soluble salts is under development. The programme simulates the water uptake and swelling of a product containing sodium nitrate crystals of uniform size placed in a regular grid. The development is presented 'live' on the screen. A preliminary description of the model is available. Extensions of the model will include diffusive leaching of soluble salts and activity through the channels in the generated spongy material and possibly facilities for handling non-uniform crystals.

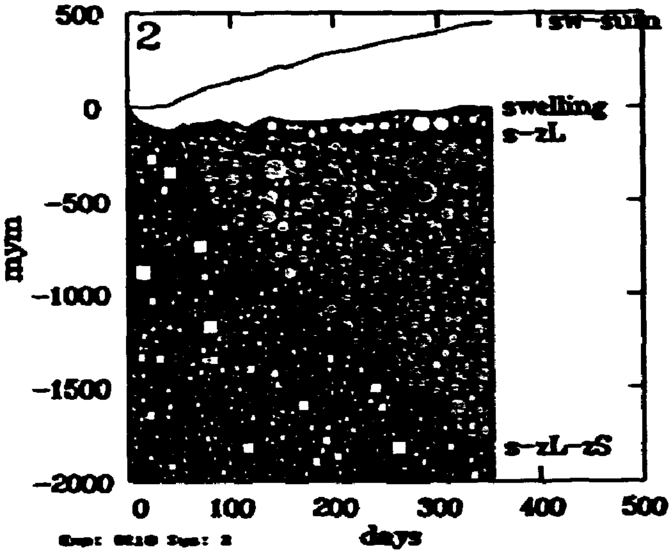


Figure 4.2.1. Example of the presentation from a water uptake and swelling experiment. The bituminized product contains 20% soluble $NaNO_3$ (10-100 μm) and 30 % $BaSO_4$ insoluble (~1 μm) crystals. The unchanged material with the size distribution of sodium nitrate crystals is represented by the area with square boxes. The sample was stored dry for the first 50 days resulting in a slight contraction due to out-diffusion of trapped gases. After immersion in water, two layers are assumed to be created, an upper one with bubbles filled with water, and a lower one filled with saturated sodium nitrate solution. Each bubble contains the volume corresponding to solution of one of the soluble salt crystals. The sw-sum curve represents the swelling calculated from the measured water uptake, thereby eliminating the effect of the simultaneous contraction. The swelling of this sample is relatively slight.

The experiments and the model were presented at working group meetings in San Sebastian and at Risø in the autumn 1993. Originally the contract was foreseen to last only for two years, but it has been extended to four years to lend theoretical support to the more practically oriented studies carried out at Cadarache and at Mol.

4.2.2 Properties of Cementitious Materials

Work under the CEC contract on »The Performance of Cementitious Barriers in Repositories« has been continued as a cooperative project between AEA Technology, Harwell, and Risø. The first two annual reports are available and a third is in preparation but it will probably be included in the final report which should be available at the end of 1994.

The experiments at Risø are mainly concerned with crack filling in cementitious barriers due to flow of calcium bicarbonate containing water. A total of 25 different samples have been studied covering a variety of crack geometries and cement mortar and solution compositions.

The mechanisms determining whether a crack is closed or not are now fairly well understood. The tendency to crack closure increases with the content of easily diffusing alkali metal hydroxides in the cement mortar and is also increased by the presence of side cracks to the main crack with the solution flow. Such side cracks, or the more complex crack systems in partly crushed samples, functions as additional sources for the OH^- ions needed for precipitation of calcium carbonate from bicarbonate solutions.

When the OH^- ions have to be supplied by dissolution of calcium hydroxide or the hydrated calcium silicates present in the wall of the main crack, the result is often the formation of a relatively thin protective layer of calcium carbonate on the surfaces of the crack permitting an nearly unchanged flow of bicarbonate solution through the middle. From a safety point of view this raises considerable uncertainties about the high pH retardation effects expected for many radionuclides in cementitious systems.

The formation of such covering layers results in very steep OH^- concentration gradients over the layer. That this must be the case can be understood from a consideration of the precipitation reactions, the diffusivities for the involved cations and anions, and the requirement of electro neutrality. A numerical diffusion model covering these features has been set up and it functions reasonably well although the steep gradients are rather difficult to model. The cement chemistry assumed in the model is simplified, and the model will not be able to handle leaching by pure water.

Characterization of the crack-filling materials was carried out using chemical analyses and scanning electron microscopy (with kind assistance from the Materials Research Department). The morphology of the precipitates from tap water was found to be different from precipitates formed from the synthetic calcium bicarbonate solution normally employed. An example is shown in Figure 4.2.2. The reason can be the presence of small amounts of magnesium minerals precipitated from the tap water. The change in morphology might influence the formation as well as the diffusive properties of the covering layer.

Figure 4.2.2. Scanning electron micrograph of the covering surface layer precipitated from flowing tap water inside a crack in cement mortar. The bar is 10 µm long. The minerals were not identified, but the main component is $CaCO_3$. The shape of the crystals is very different from the much more regular box-shaped crystals precipitated from synthetic calcium bicarbonate solution.

In some experiments with flow of deionized water into thin cracks it was demonstrated that crack closure might occur also under such circumstances. The reason is probably formation of voluminous silica gel as a degradation product from leaching of the cement mortar.

The influence of deionized water on leaching and relocation of materials within columns containing granulated cement paste of various types (and partly prepared from activated cement) was also investigated.

The measurements made by the Chemistry Section using SANS (small angle neutron scattering) to characterize the microstructure of cement paste degraded by leaching have been reevaluated using new calculation techniques. This has improved the presentation and seems to indicate that the SANS-signal over a wide range of treatments is dominated by micro-porosity in the remaining C-S-H phase in the paste. There is some interest for additional SANS work on cementitious materials at the University of Aberdeen and at Saclay. Results from the studies were presented at working group meetings at San Sebastian and at Risø.

The experimental method employed in the crack filling experiments is versatile and may be developed for various purposes. One example is the contributions to the CEC contract expected in 1994 under the PECO programme from the Nuclear Research Institute Rez, the Czech Republic. They will use the method in combination with radon as a tracer to study the diffusivity of a non-ionic species in the layer of precipitate. Other variations might be proposed for the new EU research programme on radioactive waste, where it is hoped that some continued more fundamental research on cementitious materials might be carried out.

The migration of chloride into concrete is important for the initiation of corrosion of embedded reinforcement steel. A contribution describing methods for the study of chloride diffusion in cementitious materials have been written for a working group set up by the Danish Concrete Association. The report from the group should give a comprehensive review of Danish experience with chloride initiated corrosion in concrete. Cracks, especially dead-end cracks, are important in this connection and some experiments using a modified version of the above-mentioned method might be of interest.

4.2.3 Waste from Large Accidents

The Nordic KAN2 project is an evaluation of possibilities and problems in connection with handling of the large amounts of contaminated soil and vegetation which may have to be disposed of as radioactive waste after a large nuclear accident.

The Waste Management Section has contributed to the project with experimental studies of interactions between contaminated soil and cement. Some interesting chemical effects of contact between the two types of materials on the release rates for strontium and cesium radioisotopes were demonstrated. Concrete is a better barrier material for strontium than soil while the opposite normally is the case for cesium. Cement solidification of some types of soil is possible but hardly feasible on a large scale.

Primitive local burial systems in the form of trenches or mounts are likely to be used for soil mixed with contaminated vegetation collected after large acidents. The influence of decaying organic materials on the release rates for strontium and cesium radioisotopes was studied using columns of soil mixed with grass. Strontium and to some degree also cesium releases were found to be enhanced in the mixed systems.

Two background reports and a contribution to the final report for the Nordic KAN2 project were written in 1993. The final report will be available in 1994.

4.3 Soil Chemistry

The above-mentioned column experiments with decaying organic materials in unsaturated soil may serve as transition to more general studies on soil chemistry carried out by the Waste Management Section.

The main objective is the development of a model for the elemental turnover in soils and plants in a forest area. It is made for the Ecology Section under the NECO project (Nitrogen Deposition, Turnover and Effects in Coniferous Forests Ecosystems) financed by the Danish Strategic Environmental Research Programme.

The SAMUS model (single area model of unsaturated soil) is based on the ECCES model previously developed at Risø. Acidification effects, percolate composition and plant uptake are modelled. The programme has been modified to handle a dynamic system (growth and harvest in a forest) and the use of shorter time steps (two days) to accomodate a more advanced hydraulic description presently available as a separate module.

4.4 Publications

4.4.1 Publications in International Journals, Proceedings and Reports

Brunel, G.; Brodersen, K.; Gens, R.; Nomine, J.C.; Iseghem, P. van, Charateristics of bituminized radioactive waste. Annual progress report 1992. (Centre de Cadarache, Saint Paul Lez Durance, 1993) vp.

Harris, A.W.; Brodersen, K.; Cole, G.B.; Nickerson, A.K.; Nilsson, K.; Smith, A.C., The performance of cementitious barriers in repositories. Annual progress report. (Commission of the European Communities, Brussels, 1993) vp.

4.4.2 Risø Reports

Brodersen, K., Cement solidification of soil and interactions between cement and radioactive contaminated soil. Risø-I-721(EN) (1993) 67 p.

Brodersen, K., Release of cesium, strontium and europium from soil columns with decaying organic material. Risø-I-722(EN) (1993) 23 p.

Carugati, S.; Brodersen, K., »Driftsrapport for Behandlingsstationen med tilhørende lagre.« Perioden 1/1 til 31/12-1993. Risø (in preparation) (in Danish).

Majborn, B.; Brodersen, K.; Højerup, C.F.; Heikel Vinther, F. (eds.) Nuclear Safety Research Department annual progress report 1992. Risø-R-679(EN) (1993) 29 p.

4.5 Lectures at Conferences and Meetings

Brodersen, K., Diffusion of $^{36}Cl^-$ in ordinary cement mortar and densit. Nordisk miniseminarium om klorindträngning i betonkonstruktioner. Chalmers Tekniska Högskola, Göteborg, (SE), 13-14 Jan 1993. Unpublished. Abstract available

Brodersen, K., The physical properties of bitumen and their importance for the use of bitumen as matrix material. 6. Progress meeting for Task 3 of the EC research programme on radioactive waste management, San Sebastian (ES), 31 Mar - 2 Apr 1993. Unpublished. Abstract available.

Brodersen, K., Crack healing in concrete. 7. Progress meeting for Task 3 of the EC research programme on radioactive waste management, Risø (DK), 28-29 Sep 1993. Unpublished. Abstract available.

Brodersen, K.; Carugati, S., Swelling and swelling pressure due to water uptake in bituminized sodium nitrate and modelling of such systems. 7. Progress meeting for Task 3 of the EC research programme on radioactive waste management, Risø (DK), 28-29 Sep 1993. Unpublished. Abstract available.

Brodersen, K.; Nilsson, K., Crack healing in concrete and SANS studies. 6. Progress meeting for Task 3 of the EC research programme on radioactive waste management, San Sebastian (ES), 31 Mar - 2 Apr 1993. Unpublished. Abstract available.

Appendix 1

Staff of the Department 1993

Head of Department

Benny Majborn

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Inge Blyitgen
Margit Nielsen
Lis Rasmussen

Health Physics Section

Scientific Staff

Anders Damkjær (head of section, from September 1)
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Jens Borg (Ph.D.student, from March 1)
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Poul Christensen
H.L. Gjørup (consultant)
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Finn Jørgensen
Frode Lund (temporary, until April 27)
Finn Pedersen
Lis Sørensen
Finn Willumsen

Guest Scientists

Geoff A.T. Duller (March 1-27 and June 1-5), University College of Wales
Högne Jungner (May 3-21 and November 1-12), University of Helsinki, Finland
Barbara Mauz (from September 8), Max Planck Institute, Heidelberg, Germany

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A. Bujor (Ph.D.student)
Peter Bille Fynbo
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Jørgen Olsen (consultant)
Knud Ladekarl Thomsen

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Benny Andreasen (temporary, until June 16)

M.Sc. Students

Kirsten H. Nielsen (until January 31)

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Scientific Staff

Knud Brodersen (head of section)
Massimo Steen Carugati

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Bent Willumsen
Arne Vinther
Ruth Aagesen

Appendix 2

Participation in International Committees

IAEA, The International Atomic Energy Agency

INES Users Group (Becher)
Nuclear Regulators Working Group (Becher)

ICRP, International Commission on Radiological Protection

Committee 4, Application of the Recommendations (Gjørup)

OECD, Nuclear Energy Agency

CSNI, Steering Committee (Højerup)
CSNI-PWG4, Confinement of Accidental Radioactive Releases (Fynbo)
NEA-NSC, Nuclear Science Committee (Højerup)
NEA-Data Bank Executive Group (Højerup)

CEC, Commission of the European Communities

CGC 6 Nuclear Fuel Cycle (Brodersen)
ACPM for Plan of Action (Brodersen)
Task 3 of the Waste Research Programme (Brodersen)
Reactor Safety Working Group (Becher)
LWR Safety Research Index Group (Nonbøl)
Working Party on Criteria for Recycling Materials from the Dismantling of Nuclear Installations (Heikel Vinther)
Group of National Experts on Assistance in the Event of a Nuclear Accident or Radiological Emergency (Heikel Vinther)
Article 37 Group of Experts (Walmod-Larsen)
Expert Group on Transfrontier Emergency Planning (Walmod-Larsen)
Expert Group on Environmental Gamma Monitors (Bøtter-Jensen)
Group of Technical Experts on Radiation Protection Dosimetry (Christensen)
EURADOS, Skin Dosimetry (Christensen)
EURADOS, Criticality Accident Dosimetry (Majborn)

Nordic Co-operation

Steering Committee for NKS Projects (Heikel Vinther)
Reference Group on KAN Projects (Brodersen)
NKS/SIK3 Project Group (Nonbøl)

Editorial Boards

Radiation Measurements (Bøtter-Jensen)
Radiation Protection Dosimetry (Bøtter-Jensen)
Nuclear Europe Worldscan (Fynbo)
Standing Committee of the 10th and 11th Solid State Dosimetry Conferences (Bøtter-Jensen)

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Abstract (Max. 2000 characters)

The report describes the work of the Nuclear Safety Research Department during 1993. The activities cover health physics, reactor physics, operation of the small reactor DR1, and radioactive waste management.

Lists of staff and publications are included together with a summary of the staff's participation in international committees.

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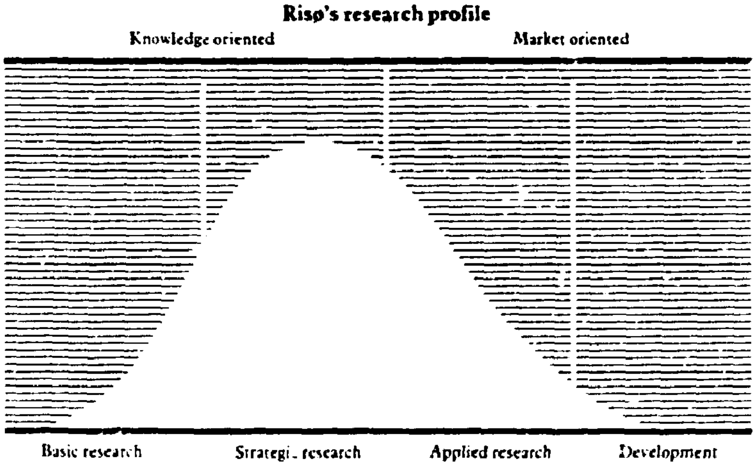

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